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Volumetric three-dimensional computed tomographic evaluation of the upper airway in patients with obstructive sleep apnoea syndrome treated by maxillomandibular advancement

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Abstract

Obstructive sleep apnoea syndrome is the periodic reduction or cessation of airflow during sleep together with daytime sleepiness. Its diagnosis requires polysomnographic evidence of 5 or more episodes of apnoea or hypopnoea/hour of sleep (apnoea/hypopnoea index, AHI). Volumetric 3-dimensional computed tomographic (CT) reconstruction enables the accurate measurement of the volume of the airway. Nasal continuous positive airway pressure (CPAP) is the conventional non-surgical treatment for patients with severe disease. Operations on the soft tissues that are currently available give success rates of only 40%-60%. Maxillomandibular advancement is currently the most effective craniofacial surgical technique for the treatment of obstructive sleep apnoea in adults. However, the appropriate distance for advancement has not been established. Expansion of the air-flow column volume did not result in an additional reduction in AHI, which raises the important issue of how much the maxillomandibular complex should be advanced to obtain an adequate reduction in AHI while avoiding the risks of overexpansion or underexpansion. We have shown that there is a significant linear relation between increased absolute upper airway volume after advancement and improvement in the AHI ($p=0.013$). However, increases in upper airway volume of 70% or more achieved no further reduction in the AHI, which suggests that the clinical improvement in AHI reaches a plateau, and renders further expansion unnecessary. This gives a new perspective to treatment based on the prediction of changes in volume, so the amount of sagittal advancement can be tailored in each case, which replaces the current standard of 1 cm.

Keywords: OSAS; Sleep disorders; Maxillomandibular advancement

Introduction

Obstructive sleep apnoea syndrome is defined as the periodic reduction or cessation of airflow during sleep together with daytime sleepiness. It is characterised by repetitive episodes

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of pharyngeal collapse with increased airflow resistance during sleep. The diagnosis requires the polysomnographic evidence of 5 or more or more episodes of apnoea or hypopnea/hour of sleep (apnoea/hypopnea index (AHI)) together with physical complaints during the day.

Risk factors include obesity, male sex, advancing age, and anatomical factors such as craniofacial abnormalities, macroglossia, hypotonia of the oropharyngeal soft tissues, retropositioning of the base of the tongue, mandibular hypoplasia and retropositioning related to posterior positioning of the hyoid and geniohyoid muscle, and maxillary retrusion. Patients with craniofacial stenosis or severe mandibular retrusion have coarctation of the 3-dimensional airway as a result of retrusion of the craniofacial complex.[1]

Obstructive sleep apnoea is associated with high cardiovascular and cerebrovascular morbidity and mortality, as well as excessive daytime sleepiness, fatigue, and neurocognitive deficits. When left untreated, the 15-year mortality approaches 30%. [2,3] Nasal continuous positive airway pressure (CPAP) is the conventional non-surgical treatment. [4] Several operations can now be done on the soft tissues to increase the posterior airway space and treat the apnoea in the 50% of patients who cannot tolerate CPAP. However, the reported success rates of these procedures are only about 40%–60%. [5]

In the early 1980s there were several reports of improved polysomnographic measures in patients having mandibular osteotomy with advancement.[6,7] However, maxillomandibular advancement (MMA) was championed over mandibular osteotomy alone to treat non-syndromic patients with sleep apnoea by the mid-1980s because it preserves the maxillomandibular relations and acknowledges the common involvement of mandibular and maxillary deficiency in the aetiology of obstructive sleep apnoea. [8,9] The operation results in enlargement of the pharyngeal space by expanding the skeletal framework to which the pharyngeal soft tissue and tongue are attached. This results in reduced pharyngeal collapsibility during negative pressure inspiration. [10,11] Enlargement of the airway after MMA has been shown by lateral cephalometric radiography, three-dimensional computed tomography (CT), and magnetic resonance imaging (MRI).[10,12–15] MMA is currently the most effective surgical technique for the treatment of obstructive sleep apnoea in adults. [16,17] Criteria used to evaluate surgical success include an AHI of 20 or less, and 50% or moe reduction in the AHI postoperatively.[5] Three-dimensional geometrical reconstruction and computational fluid-dynamic simulations have been used to predict the amount of surgical movement needed to achieve adequate upper airway volume.[18]

However, the appropriate amount of advancement has not been established, which leaves many issues unresolved, such as whether the maxillomandibular unit should be advanced as much as possible, whether it should be done in the same way in every patient, and whether it should be done independently of preoperative anatomical conditions. The objective of this retrospective study was therefore to analyse volumetric changes in the upper airway after MMA in patients with obstructive sleep apnoea using 3-dimensional CT and to examine the relation between these changes and reductions in AHI.

Material and methods

Patients

This retrospective study involved 10 consecutive men (mean (SD) age 45 (14), range 16–59 years) with obstructive sleep apnoea who had MMA at the Maxillofacial Surgery Unit of S. Orsola-Malpighi Hospital, Bologna, Italy, between July 2008 and January 2011. They all had moderate or severe disease diagnosed by polysomnography according to established variables. [1]

Examinations

All patients had routine preoperative examinations, polysomnography, Muller's manoeuvre, sleep endoscopy, and CT with cephalometric analysis.

Polysomnography was done to calculate AHI preoperatively and 6 months postoperatively during standard, overnight sessions. Muller's manoeuvre, in which the patient attempts to inhale with the mouth closed and the nostrils plugged, induced airway collapse, and was designed to identify collapsed sections of airway such as the trachea and upper airways with a flexible fibreoptic endoscope inserted into the hypopharynx. This was used to help find out the cause of the sleep apnoea. Sleep endoscopy, which enables dynamic evaluation of the upper airway, was used to ascertain the site(s) of collapse during respiratory events. CT was done preoperatively and 6 months postoperatively to evaluate the anatomy of the upper airway. Images were acquired with a high-speed CT scanning station (General Electric; 3.0-mm slice interval, 1.5-mm overlap) while patients were awake supine and in a neutral position (including standard head position) during one breath hold at the end of a normal inspiration, as proposed by many authors. [9]

The following limits for upper airway volume were adopted in accordance with Ogawa et al:[19] cephalad=hard palate plane; caudad=inferior margin of the hyoid; ventral=junction of the superior adenoid tissue and nasopharynx; dorsal=posterior pharyngeal wall; and lateral=right and left lateral pharyngeal walls. The range of upper airway volumes was extrapolated postoperatively using 3-dimensional CT images and reconstruction software (Simplant View; Materialise, Leuven, Belgium).

Operation

All patients were operated on under general anaesthesia with nasopharyngeal intubation. The operation was undertaken through a Le Fort I osteotomy with a standard advancement

Table 1
Upper airway volumes (obtained by 3-dimensional volumetric reconstruction) and apnoea/hypopnea indices before and after maxillomandibular advancement.

Case No.	Upper airway volume (ml)			Apnoea/hypopnoea index (per hour of sleep)		
	Preoperative	Postoperative	Change (%)	Preoperative	Postoperative	Change (%)
1	17.5	25.9	+8.4 (+48.0)	60.0	10.0	-50.0 (-83.3)
2	10.9	17.8	+6.9 (+63.9)	49.7	9.0	-40.7 (-81.9)
3	8.0	15.5	+7.5 (+93.8)	58.3	8.1	-50.2 (-86.1)
4	11.0	17.2	+6.2 (+56.4)	54.5	15.0	-39.5 (-72.5)
5	21.0	26.4	+5.4 (+25.6)	65.0	23.0	-42.0 (-64.6)
6	9.7	22.2	+12.5 (+128.8)	61.0	10.0	-51.0 (-83.6)
7S	9.6	20.5	+10.9 (+114.0)	93.1	14.0	-79.1 (-85.0)
8	13.5	21.5	+7.9 (+58.6)	40.0	3.7	-36.3 (-90.8)
9	13.2	19.1	+5.9 (+45.0)	56.0	12.0	-44.0 (-78.6)
10	14.7	20.9	6.2 (41.8)	30.0	18.3	-11.7 (-39.0)
Mean (SD)	12.9 (4.0)	20.7 (3.5)	7.8 (2.3) (67.6(33.5))	56.8 (16.6)	12.3 (5.5)	-44.5 (16.6) (-76.5(15.1))

of 10 mm, checked with an intermediate surgical splint. Bilateral sagittal split osteotomy of the mandible with the same advancement was then done, and final occlusion was obtained using a final surgical splint. Osteosynthesis was obtained using four x 2.0 miniplates for the maxilla and two x 2.7 bicortical screws on each side for the mandible.

Ethics

The study protocol conformed to the guidelines of the World Medical Association Declaration of Helsinki, 2008. This study did not require institutional review board approval because data were collected from patients treated according to usual clinical practice who provided written or oral informed consent for each medical procedure.

Statistical analysis

The data are expressed as mean, SD, and ranges. The Wilcoxon matched-pairs rank test was used to compare preoperative and postoperative data, and Spearman's rank correlation was used to test relations between upper airway volumes and AHI. The significances of differences were assessed on a personal computer using SPSS (version 19 for Windows; IBM Corp. Armonk, NY). Tests were 2-tailed, and probabilities of less than 0.05 were accepted as significant.

Results

All patients had severe obstructive sleep apnoea. Upper airway volume and AHI measured before and after operation by volumetric 3-dimensional CT reconstruction, and changes in these values 6 months after treatment, are shown in Table 1.

Upper airway volume

The mean (SD) volume increased significantly in all patients treated with MMA (by 67.6 (33.5)%, range 25.6%–128.8%) from the preoperative value (12.9 (4.0) ml, range 8.0–21.0 ml) compared with the value at 6 months after treatment (20.7 (3.5) ml, range 15.5–26.4 ml) Z = 2.80, p = 0.005). Fig. 1 shows the relations between volumes in the posterior airway space before and after operation. These showed almost linear proportionality (rho = 0.685, p = 0.029; Fig. 1a), but there were no significant relations in absolute volume (rho = 0.503, p = 0.138; Fig. 1b). There was a significant inverse relation between preoperative upper airway volume and the percentage increase postoperatively (rho = -0.867, p = 0.001; Fig. 1c), suggesting that proportionately much more expansion occurred in patients with smaller preoperative upper airway volumes than in those with larger ones.

Apnoea/hypopnoea index

The mean AHI decreased significantly (by 76.5 (4.8) %, range 39.0%–90.7%) from the preoperative value (56.8 (5.2)%, range 30.0%–93.1%) to the value 6 months after MMA (12.3 (5.5)%, range 3.7%–23.0%; Z = 2.80, p = 0.005; Table 1). Similarly to the pattern of increase in upper airway volumes, AHI decreased less in patients with smaller preoperative upper airway volumes than in those with larger ones, although the difference was not significant (rho = 0.419, p = 0.228; Fig. 2a; rho = 0.552, p = 0.098; Fig. 2b; rho = 0.552, p = 0.098; Fig. 2c).

Correlations between AHI and upper airway volume 6 months after treatment

We found no significant relation between preoperative and absolute upper airway volumes and AHI values 6 months after treatment (rho = 0.255, p = 0.476; Fig. 3a). There was an insignificant negative relation between absolute changes in AHI and the modifications in upper airway volume induced by operation (rho = -0.576, p = 0.082; Fig. 3b), and the latter were significantly and negatively correlated with the percentage of change in AHI (rho = -0.745, p = 0.013; Fig. 3c).

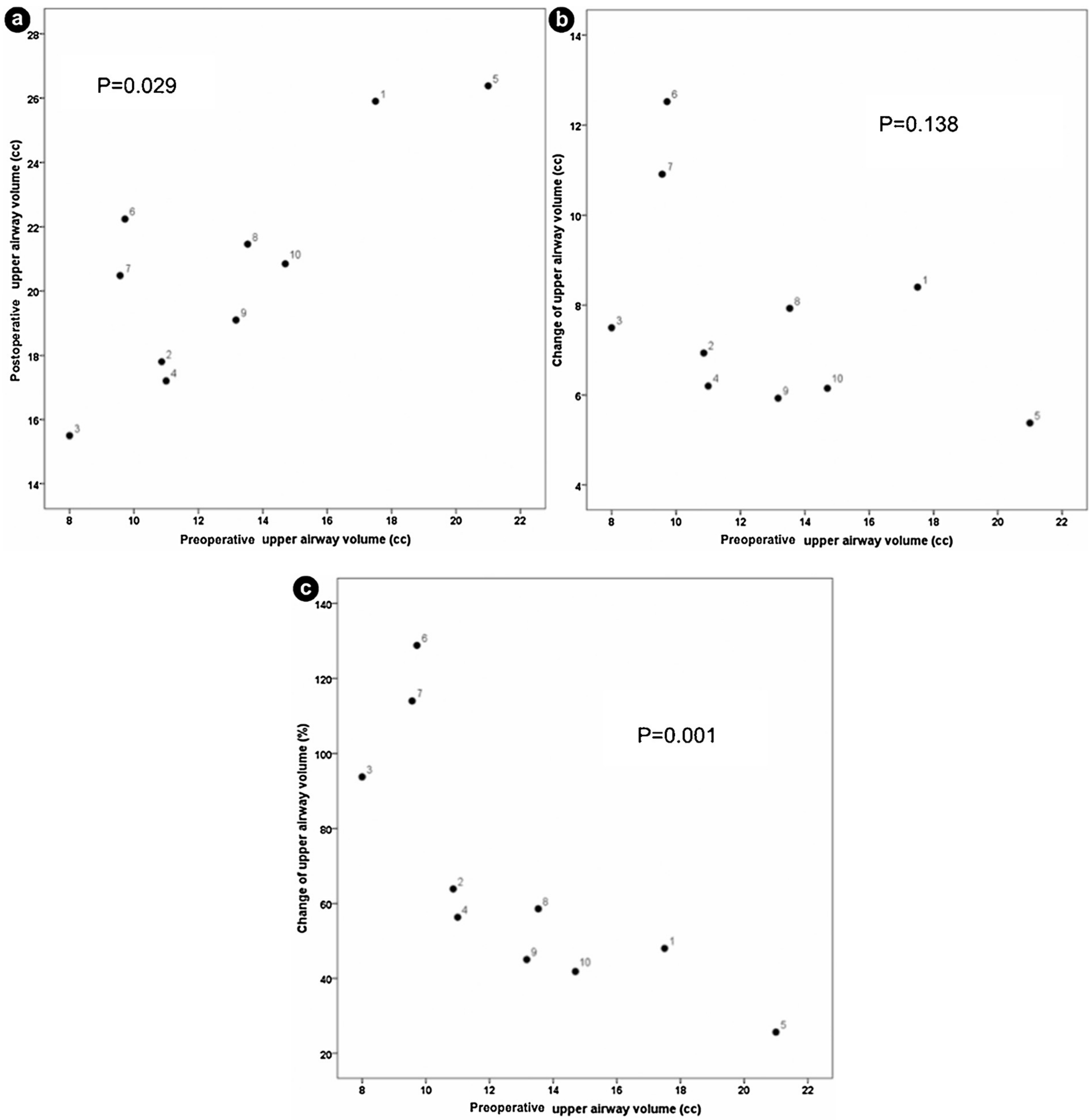

Fig. 1. Relations between preoperative upper airway volume (UAV) and (a) absolute postoperative UAV, (b) absolute change in UAV, and (c) percentage change. The two volumes had an almost linear relation (a), but there was no significant relation with the increase in absolute volume increase (b). There was significantly more proportional expansion in patients with small preoperative UAV than in those with larger UAV (p = 0.001 (c).

Discussion

Operations on the soft tissues that are currently available give success rates of only about 40%–60% .[5] Mandibular osteotomy with advancement was used in the early 1980s and gave improved polysomnographic results in patients with sleep apnoea. [5,7] However, by the mid-1980s MMA was being championed over mandibular osteotomy alone because it preserves the maxillomandibular relation and recognises the common involvement of coexisting mandibular and maxillary deficiencies in the aetiology of obstructive sleep apnoea. [8,9]

MMA enlarges the pharyngeal space by expanding the skeletal framework .[10,11] Schendel et al. confirmed that maxillary advancement pulls the velum and velopharyngeal muscles forward, [20] and Wickwire et al. noted that mandibular advancement takes the tongue and suprahyoid muscles forward. [21] Enlargement of the airway after MMA has been seen on lateral cephalometric radiography and 3-dimensional CT. Fairnburn et al., [10] and Yu et al. [22] used CT to show the lateral and anteroposterior improvement in pharyngeal restriction along the entire airway after MMA. It is currently considered to be the most effective surgical technique for the treatment of obstructive sleep apnoea in adults, [17] but we

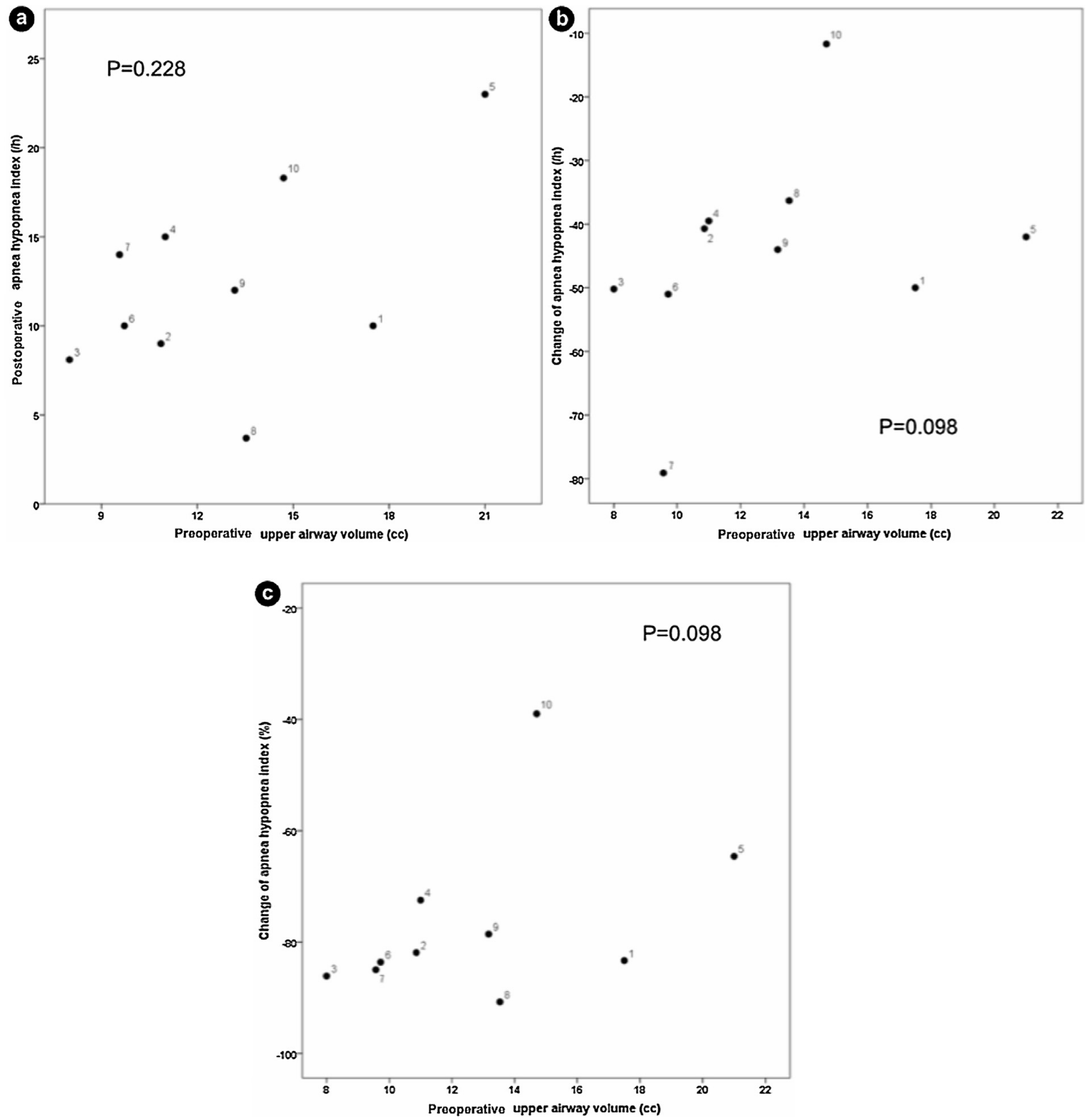

Fig. 2. Relations between preoperative upper airway volume (UAV) and (a) absolute postoperative apnoea/hypopnea index (AHI), (b) absolute change in AHI, and (c) percentage change. There was a slight but insignificant correlation between changes in AHI and UAV (b, c), p = 0.098.

know of no multicentre data, and there are few data about morbidity.

In a systematic review and meta-analysis, Holty and Guilleminault reported a significant, and clinically relevant, reduction in the AHI (63.9 (26.7) compared with 9.5 (10.7) $p < 0.05$).[2] They also found that the degree of maxillary, but not mandibular, advancement was related to success. Studies that reported success rates of less than 80% ($n = 4$) had less mean maxillary advancement than did those with higher success rates (8.4 (2.8) mm compared with 9.9 (1.3) mm; $p < 0.001$). In the same review, the authors found that success was associated with a mean maxillary advancement of 9.5 mm, compared with 7.9 mm for unsuccessful cases ($p = 0.03$),.

Individual data were used to identify female sex, lower AHI before MMA, and more maxillary advancement as univariate predictors of success. Ronchi et al. achieved good resolution of AHI in patients with class I and class II occlusions.[13] All patients were treated by MMA to produce 10 mm mandibular advancement or more measured at the incisal margin, but many patients also had other operations (such as genioplasty or septoplasty). Lye et al.,[23] found a significant correlation between the degree of maxillary advancement and reduction in AHI. Faria et al. found volumetric increases of

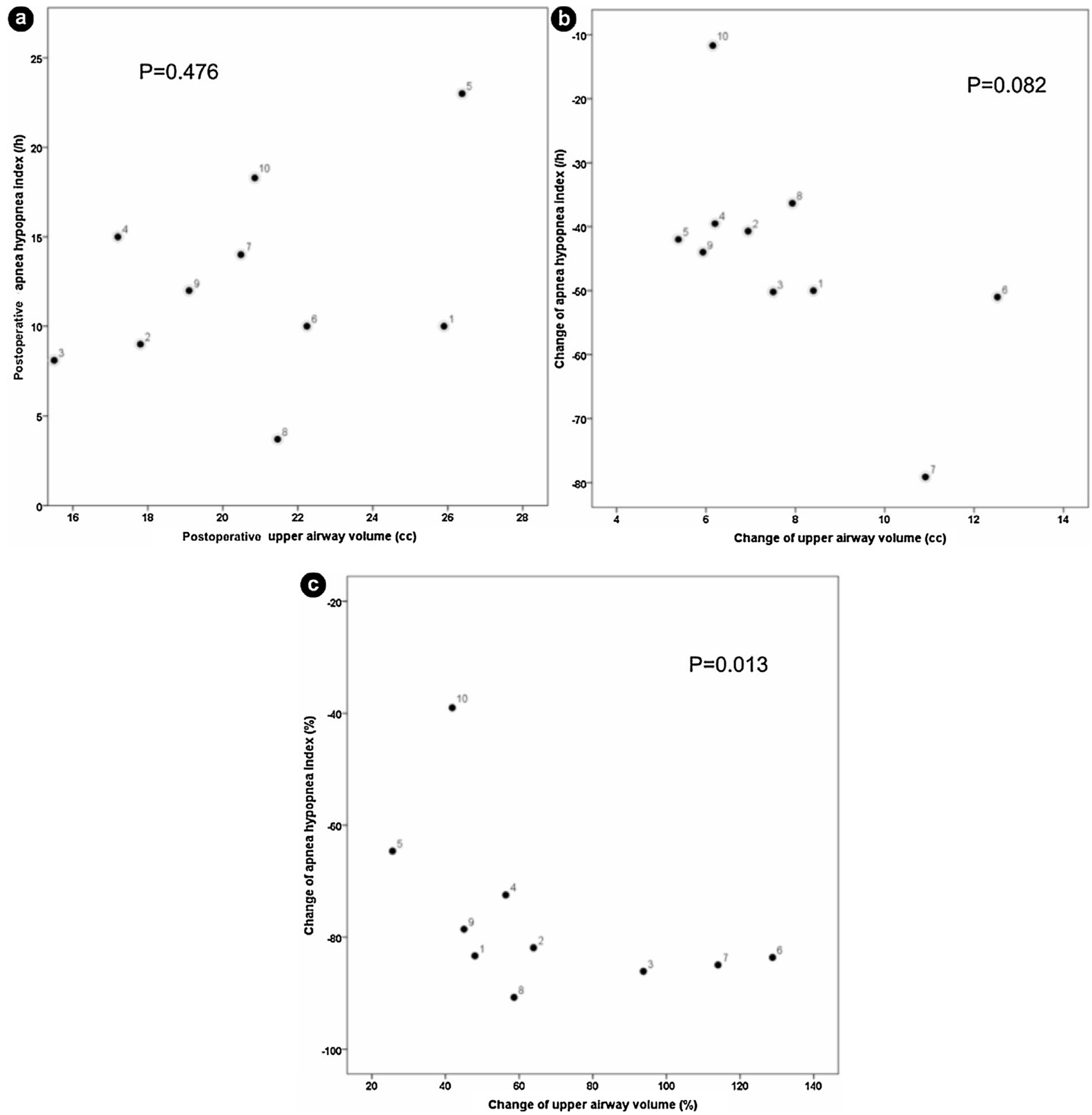

Fig. 3. Relations between the apnoea/hypopnea index and upper airway volume 6 months after treatment. Data are plotted as (a) absolute values, (b) absolute changes, and (c) percentage changes.

26.7% into the retropalatal region and 27.2% in the retrolingual region on MRI.[12] Of course, the maximum amount of MMA could risk protrusion, [24] even when surgical tricks are used to minimise this.[13]

The percentage increase in upper airway volume was extremely variable in our sample (mean 67.6%, range 25.6%–128.8%) as a result of differences in preoperative upper airway volume (mean 12.9 ml, range 8–21 ml). The percentage reduction of AHI also varied (mean 76.5%, range 39.0%–90.8%). These broad ranges can be explained biomechanically by differences in the percentage final volume increase and air flow (and therefore AHI) as a result of the expansion of different volumes in the same space.

Expansion of the air-flow column volume above 70% did not result in any additional reduction in AHI, as illustrated by the plateau in the data curve (Fig. 3c), which raises the important issue of how much the maxillomandibular complex should be advanced to obtain adequate reduction in the AHI while avoiding the risks of overexpansion or underexpansion. We noted that the achievement of a postoperative mean AHI of 12.3, which is considered to indicate success, [5,17,25] required a mean postoperative upper airway volume of 20.7 ml, with a mean volume increase of 7.8 ml (67.6%), which corresponded to about 0.8 ml/mm linear advancement within the standard advancement of 10 mm. In patients with small preoperative upper airway volumes, there was

considerably more than 0.8 ml/mm linear advancement (for example,1.25 and 1.09 ml in case numbers 6 and 7, respectively), whereas less expansion was achieved in patients with higher preoperative volumes. Our patients seemed to require proportionately more expansion than reported by Faria et al. [12] (means 67.6% compared with 26.7%), which could be explained by the higher AHI in our sample (means 59.7 compared with 30.96).

Our analysis has shown that there are significant linear relations between increased absolute upper airway volume and improvement in the AHI after MMA. However, increases in volume of 70% or more achieved no further reduction in the AHI, which suggests that the clinical improvement in AHI reaches a plateau, rendering further expansion unnecessary.

Conflict of Interest

We have no conflict of interest.

Ethics statement/confirmation of patients' permission

The study protocol conformed to the guidelines of the World Medical Association Declaration of Helsinki, 2008.

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